

# WG 1 Summary

FNAL Proton Driver Workshop  
October 9, 2004

S. Brice, D. Harris, W. Winter

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- Summary



# Session I

Purpose and setting of scene



# Neutrino oscillations as probes of GUT theories (Andre de Gouvea)

Proton Decay Workshop		$\sin \theta_{13}$	$\sin^2 2\theta_{13}$	André de Gouvêa, Northwestern University
References				
$\Delta m_{13}^2 > 0$	<i>SO(10)</i>			
	Goh, Mohapatra, Ng [40]	0.18	0.13	
“typical”	<i>Orbifold SO(10)</i>			
	Asaka, Buchmüller, Covi [41]	0.1	0.04	[from reactor white paper]
prediction	<i>SO(10) + flavor symmetry</i>			
	Babu, Pati, Wilczek [42]	$5.5 \cdot 10^{-4}$	$1.2 \cdot 10^{-6}$	The literature on this subject is very
of all*	Blazek, Raby, Tobe [43]	0.05	0.01	
	Kitano, Mimura [44]	0.22	0.18	large. The most exciting driving force
	Albright, Barr [45]	0.014	$7.8 \cdot 10^{-4}$	
Type-I	Mackawa [46]	0.22	0.18	(my opinion) is the fact that one can
	Ross, Velasco-Sevilla [47]	0.07	0.02	
GUT	Chen, Mahanthappa [48]	0.15	0.09	make <i>bona fide</i> predictions:
	Raby [49]	0.1	0.04	
models	<i>SO(10) + texture</i>			
	Buchmüller, Wyler [50]	0.1	0.04	$\Rightarrow U_{e3}$ , CP-violation, mass-hierarchy
	Bando, Obara [51]	0.01 .. 0.06	$4 \cdot 10^{-4}$ .. 0.01	
inverted	<i>Flavor symmetries</i>			unknown!
	Grimus, Lavoura [52, 53]	0	0	
hierarchy	Grimus, Lavoura [52]	0.3	0.3	Unfortunately, theorists have done too
	Babu, Ma, Valle [54]	0.14	0.08	
requires*	Kuchimanchi, Mohapatra [55]	0.08 .. 0.4	0.03 .. 0.5	good a job, and people have successfully
	Ohlsson, Seidl [56]	0.07 .. 0.14	0.02 .. 0.08	
“more	King, Ross [57]	0.2	0.15	predicted everything...
	<i>Textures</i>			
flavor	Honda, Kaneko, Tanimoto [58]	0.08 .. 0.20	0.03 .. 0.15	
	Lebed, Martin [59]	0.1	0.04	
structure”	Bando, Kaneko, Obara, Tanimoto [60]	0.01 .. 0.05	$4 \cdot 10^{-4}$ .. 0.01	More data needed to “sort things
	Ibarra, Ross [61]	0.2	0.15	
* Albright, hep-ph/0407155 (inverted hierarchy)	$3 \times 2$ sec-saw			out,” which is why we are here!
	Appelquist, Piai, Shrock [62, 63]	0.05	0.01	
Anarchy	Frampton, Glashow, Yanagida [64]	0.1	0.04	
	Mei, Xing [65] (normal hierarchy)	0.07	0.02	
Renormalization group enhancement	de Gouvêa, Murayama [66]	$> 0.006$	$> 1.6 \cdot 10^{-4}$	
	Mohapatra, Parida, Rajasekaran [67]	$> 0.1$	$> 0.04$	
October 6, 2004		0.08 .. 0.1	0.03 .. 0.04	Neutrino Oscillations and New Physics

Table 1: Incomplete selection of predictions for  $\theta_{13}$ . The numbers should be considered as order of magnitude statements.

Also: Mass hierarchy, deviations from max. mixing!

## Relationship to Low Energy Observables?

In general ...no. This is very easy to understand. The baryon asymmetry depends on the (high energy) physics responsible for lepton-number violation. Neutrino masses are one of many consequences of this physics, albeit the only observable ones at the “low-energy” experiments we are able to perform.

see-saw:  $y, M_N$  have more physical parameters than  $m_\nu = y^t M_N^{-1} y$ .

There could be a relationship, but it requires that we know more about the high energy Lagrangian (model dependent). The day will come when we have enough evidence to refute leptogenesis (or strongly suspect that it is correct) - but more information is really necessary (charged-lepton flavor violation, collider data on EWSB, lepton-number violation, precise oscillation parameter measurements, etc).

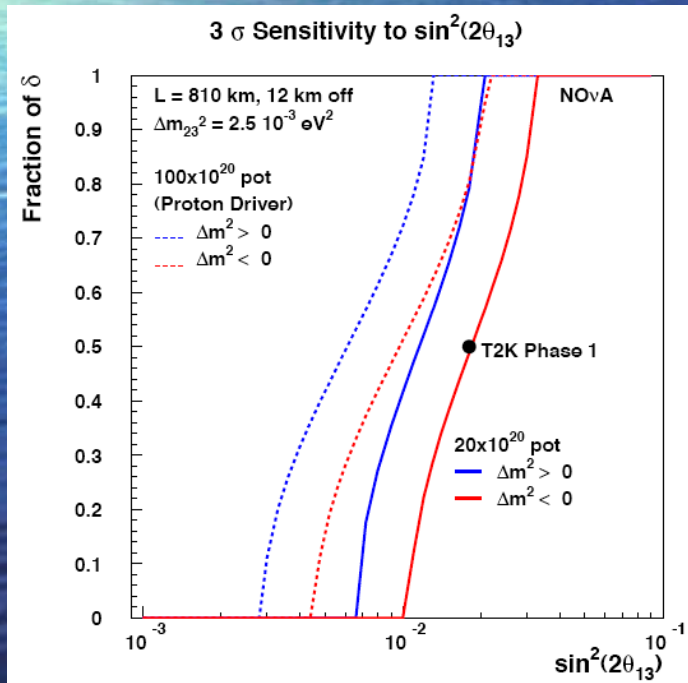
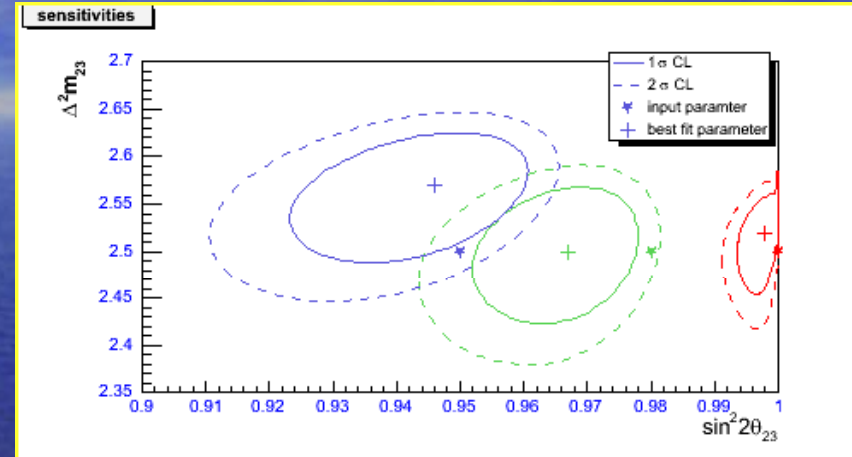
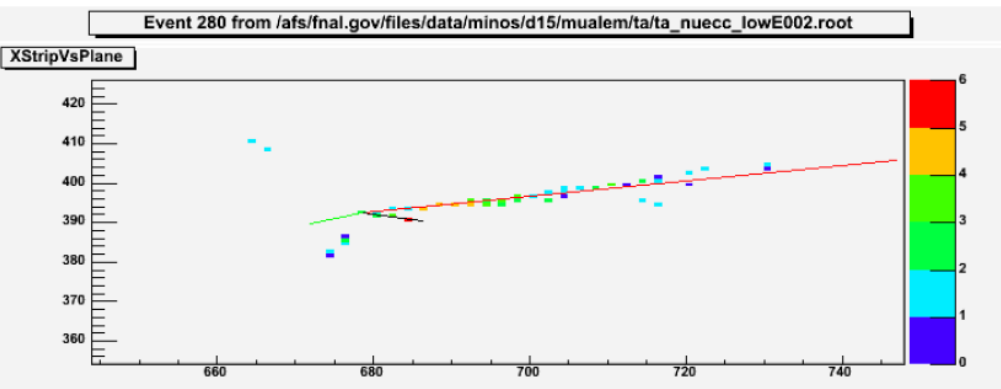


# Session II

## Superbeam Experiments I



# NOvA Vital Statistics (Feldman)

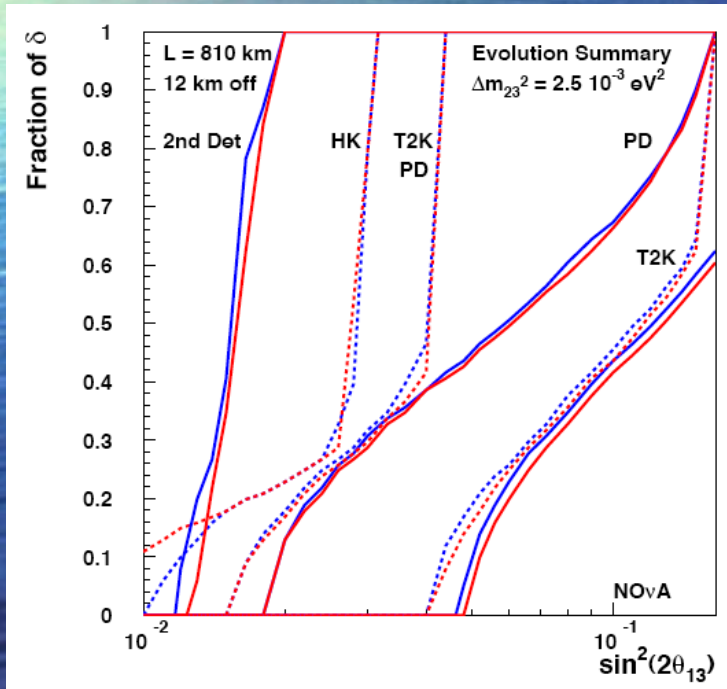


	Baseline	TASD
Mass	50 kT	25 kT
Optimized $\nu_e$ efficiency	18%	32%
Optimized s/b	4.8	7.7
s/sqrt(b)	24.5	24
Cost	\$147M	\$159M

# NOvA and the Proton Driver

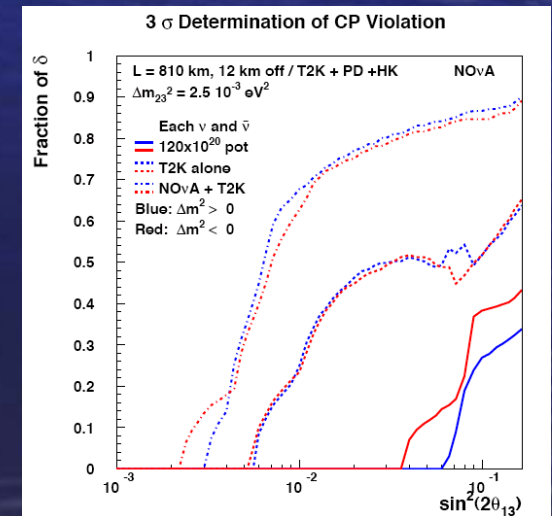
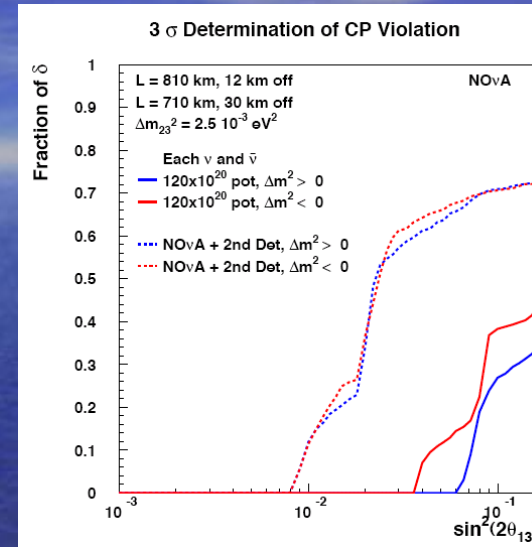
Note that a Proton Driver changes a  $1\sigma$  matter effect into a  $3\sigma$  effect:

$$\Delta\chi^2 = 2.3 \rightarrow \Delta\chi^2 = 11.8.$$



$2\sigma$  Mass Hierarchy

$3\sigma$  CP violation: 2nd detector and T2K synergy



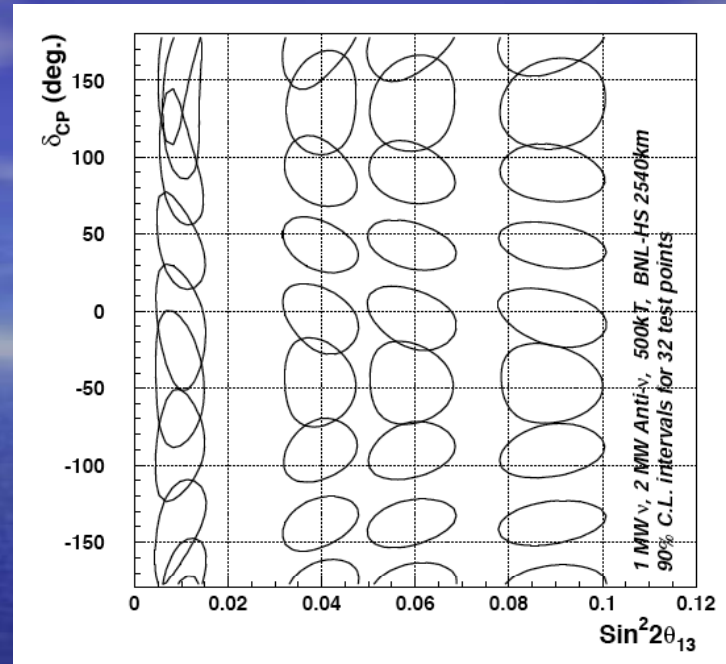


# Comparing Super-NO<sub>v</sub>A and BNL

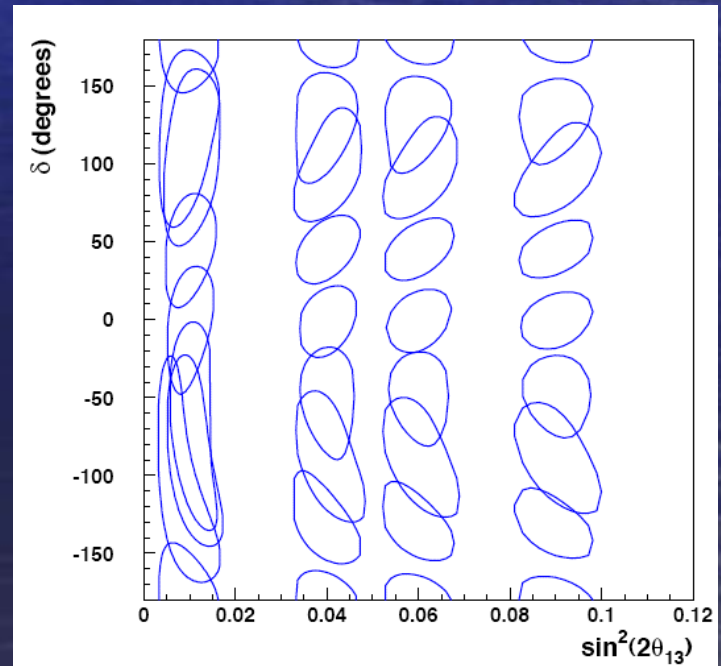
## Vigorous discussion:

- BNL proposal is not so different in MW\*kton than the NO<sub>v</sub>A+PD+2<sup>nd</sup> Det listed here
- BNL Advantage: they can see “solar term” even if  $\sin^2 2\theta_{13}=0$ ; synergy w/p decay
- NO<sub>v</sub>A+PD+2<sup>nd</sup> Det advantage: can proceed in a step-by step manner

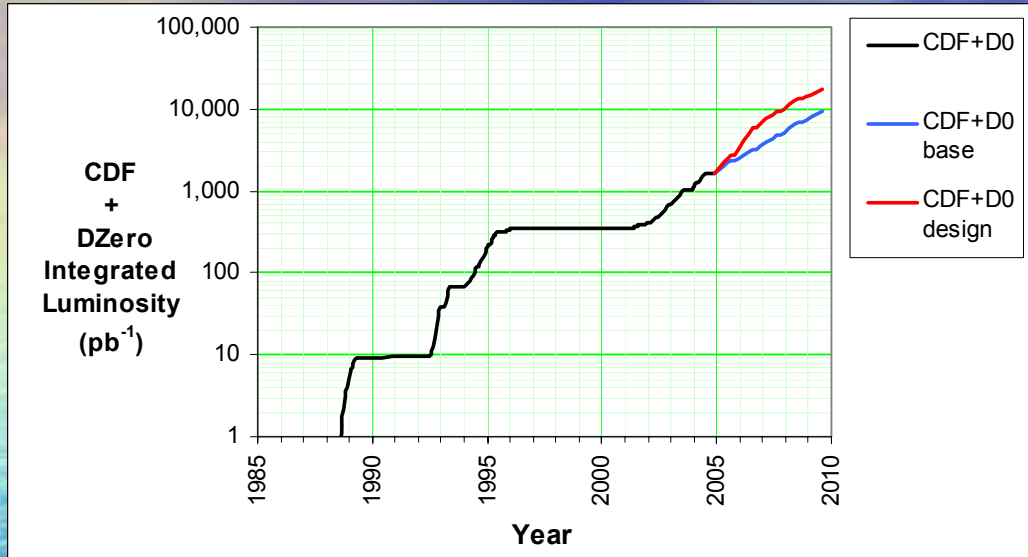
BNL Proposal



NO<sub>v</sub>A + PD + 2<sup>nd</sup> Det



# Collider/Neutrino Program Analogy (Cooper)

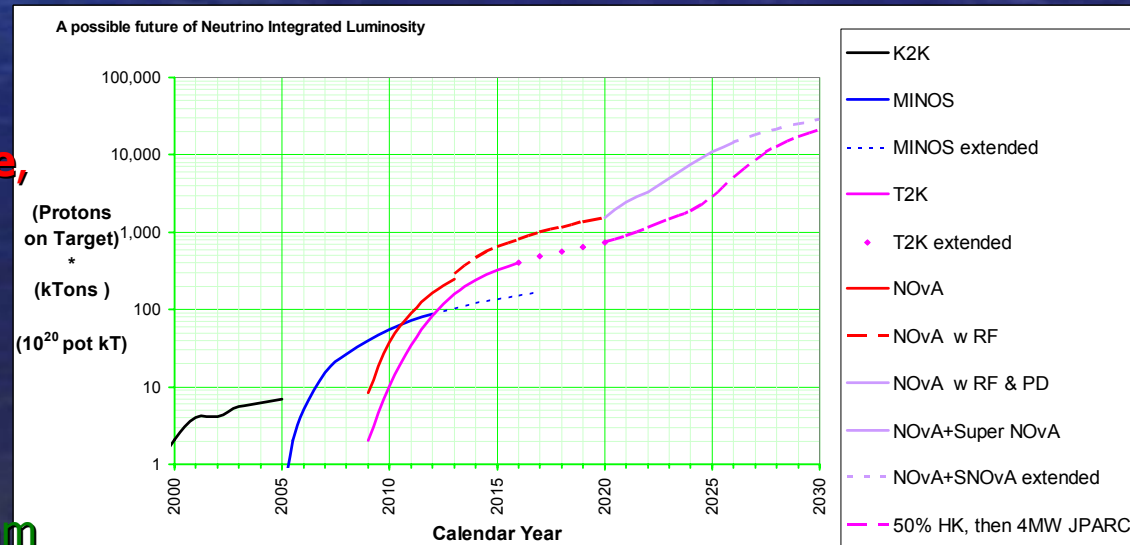


- **Integrated Luminosity doubles 14 times in 21 years (1988-2009)**

- ( $2^{14}=16,384$ ), Integrated Luminosity advances by 3<sup>+</sup> orders of magnitude

- **The original 87 CDF collaborators grew to 1500 total at CDF + DZero**

- MINOS is 10\* K2K
- **Add NOvA**, 5 \* MINOS ktors
- **Add a Main Injector RF upgrade**, 2 \* NuMI pot
- **Add a Proton Driver**, 5 \* (NuMI + MI RF) pot
- **Add SuperNOvA**, 3 \* NOvA ktors
- Overall, can get a factor >1000 (in 10<sup>20</sup> pot \* kT) in such a program



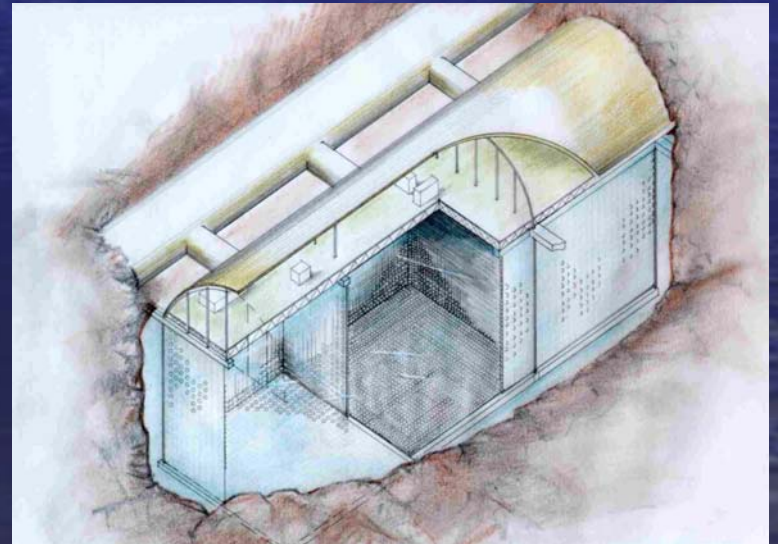
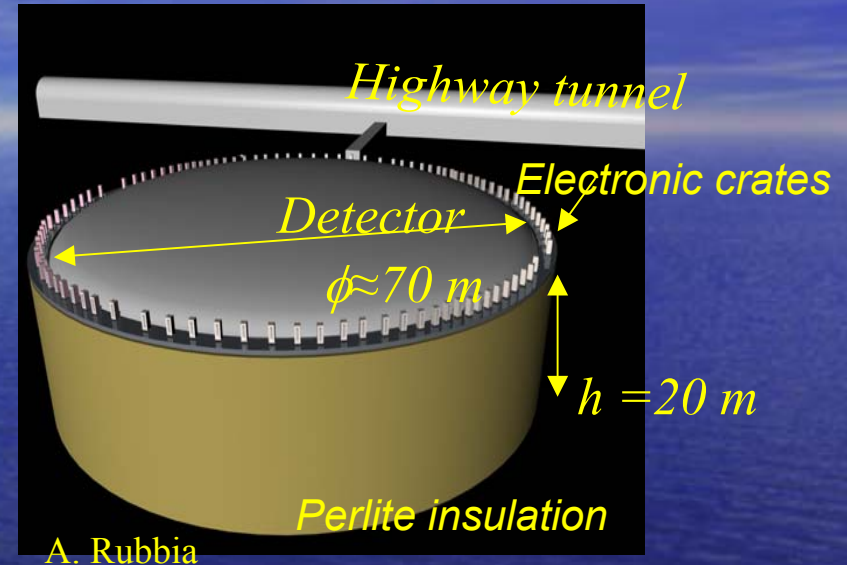
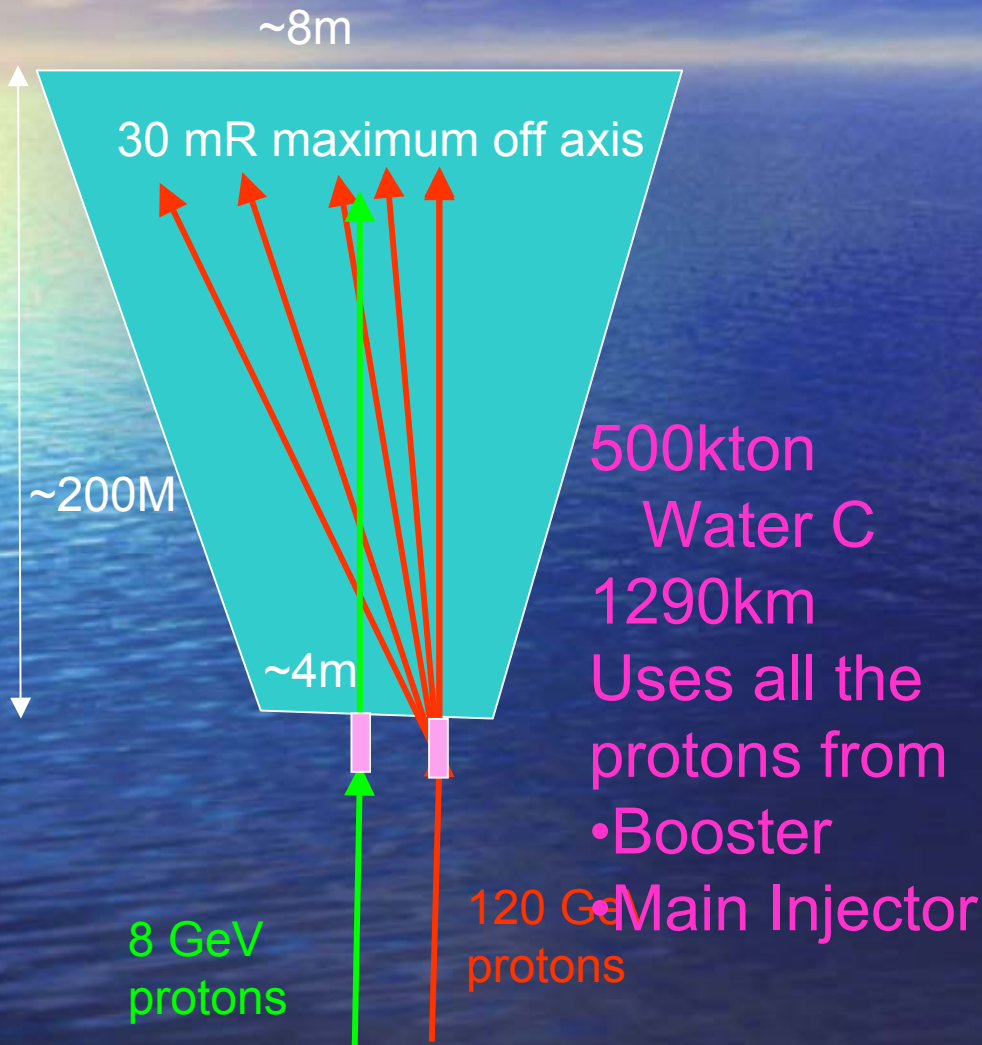


# Ah, but aren't colliders just richer than "measure one number" $\nu$ physics?

- **NO** – While  $\theta_{13}$  is the driving goal, we should not start to think of  $\theta_{13}$  like we did about the Higgs as the only justification of a program
  - Measuring  $\theta_{13}$  is like finding and measuring the top mass?
  - Determining the mass hierarchy is like a Higgs discovery?
  - Detection of CP violation in the neutrino sector is like finding SUSY ?
  - **There are other physics topics**
    - Measuring  $\sin^2\theta_{23}$  and  $\Delta m_{23}^2$  at each new level of luminosity is like measuring the W mass or B lifetimes at each new level of luminosity in the collider program
    - Searching for sterile neutrino effects at each new level of luminosity is like searching for  $Z'$  at each new level of luminosity
    - Measuring low energy  $\nu$  cross sections (DIS, quasi-elastic,...) is (like) studying QCD
    - 
    -
- **There should be plenty of  $\nu$  publications!!!**

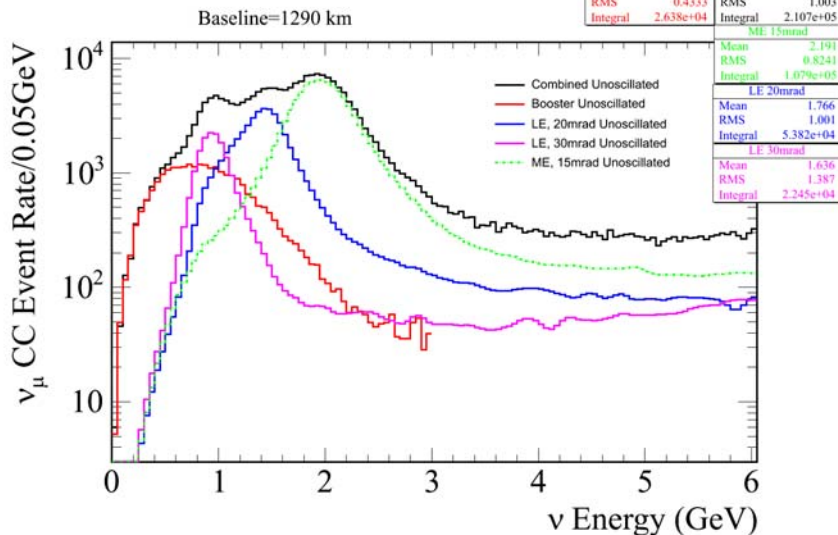


# Fermilab to Homestake (2+2)MW (D. Michael)

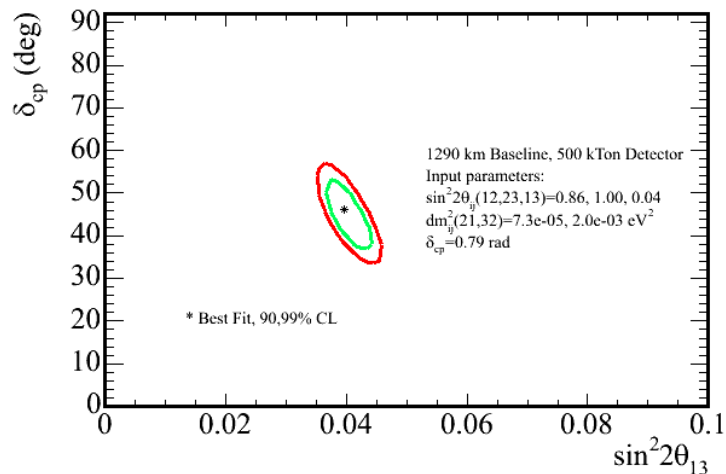
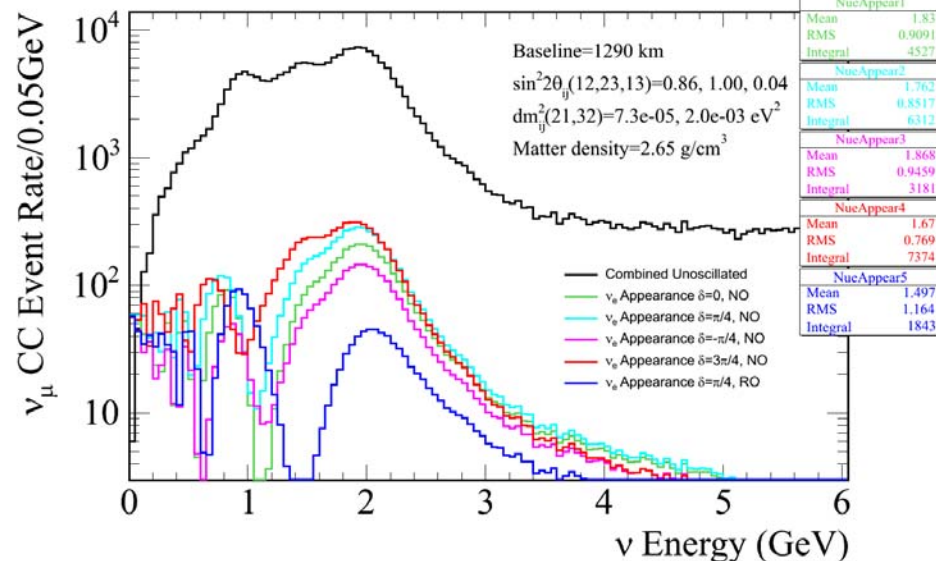


# Fermilab to Homestake (2+2)MW

CC Events: 1000e20 POT Booster, 100e20 POT MI, 500kT Detector



CC Events: 1000e20 POT Booster, 100e20 POT MI, 500kT Detector



90% CL  
99% CL



# Session III

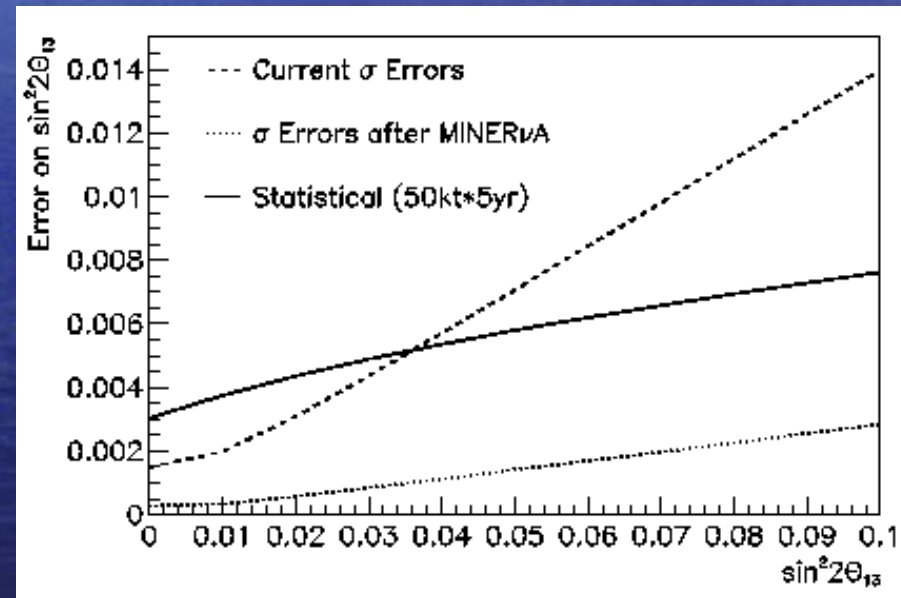
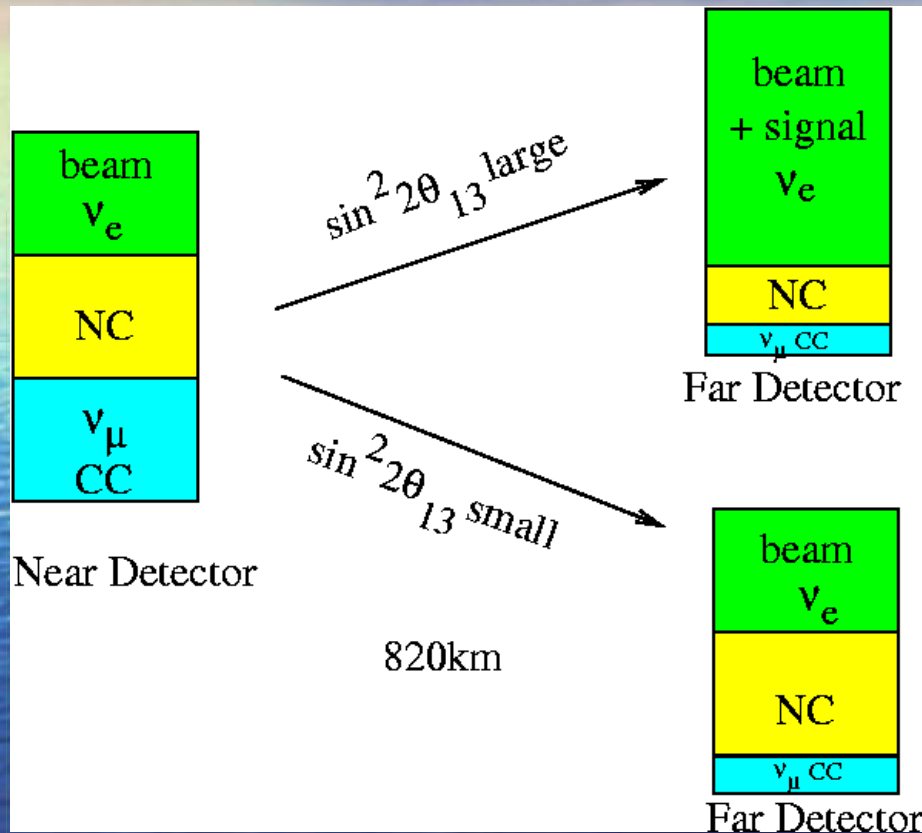
Neutrino beams  
(together with WG2:  
to be discussed there)



# Session IV

Cross section needs  
(together with WG 2)

# The Cross-Section Needs of Future Oscillation Experiments (Harris)



Moral of Story: Need Near Detector AND cross section measurements!

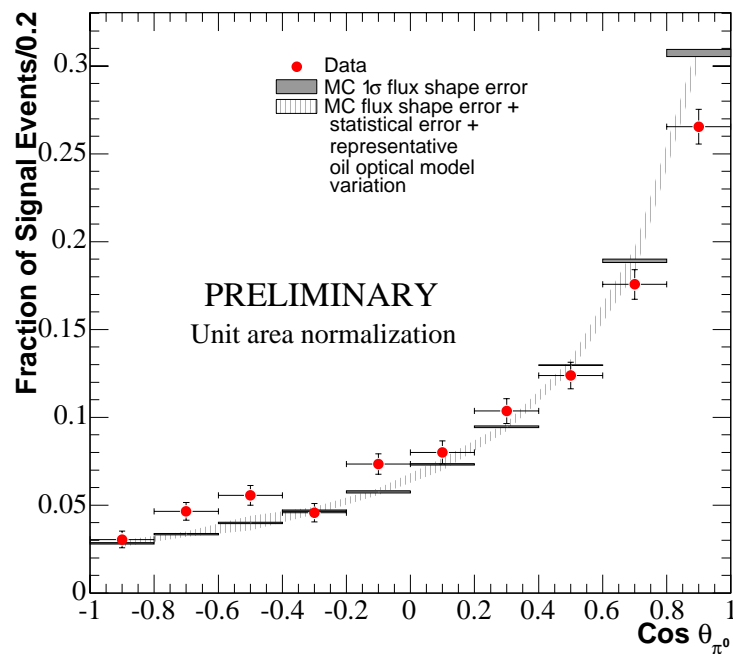
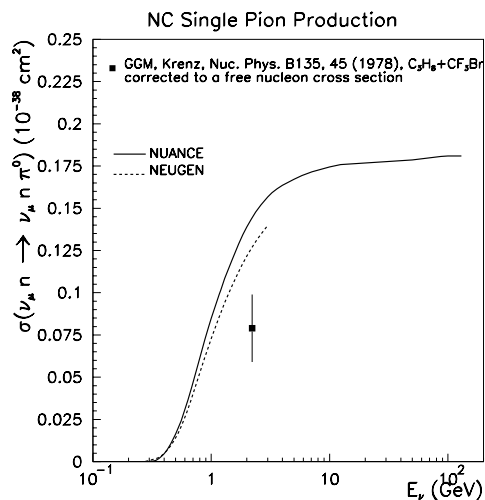
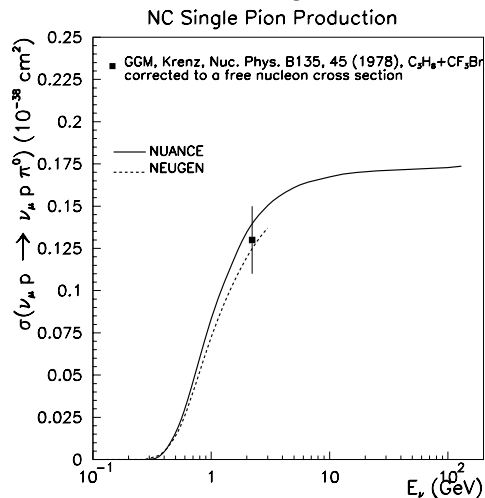
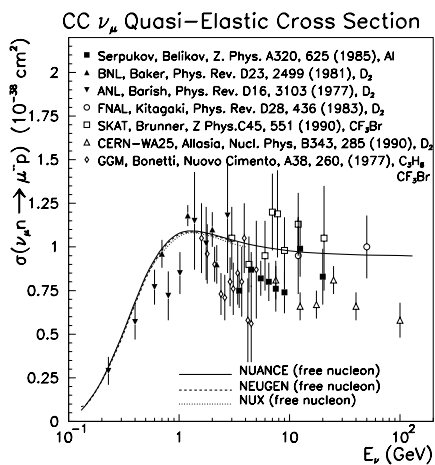
# The world's $\text{NC}\pi^0$ cross-section measurements (the dominant background in $\nu_e$ appearance)

## Status of Neutrino

## Cross Sections (Zeller)

J.Raaf, MiniBooNE  
~7000 events

Best measurements:  
CC QE



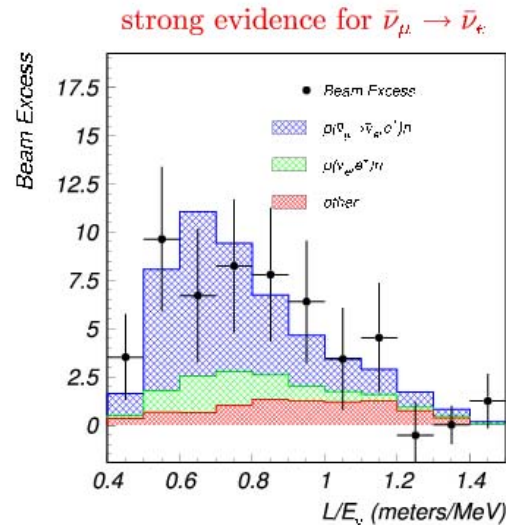


# Session V

What if MiniBOONE confirms  
LSND?

# ... does it have to be sterile?

## (The LSND Anomaly



If oscillations  $\Rightarrow \Delta m^2 \sim 1 \text{ eV}^2$ ;

- × does not fit into 3  $\nu$  picture;
- × 2 - 2 scheme “ruled out” (solar, atm);
- × 3 - 1 scheme “disfavored” (sbl searches);
- × CP1V “ruled out” (KamLAND, atm);
- ×  $\mu \rightarrow e \nu_e \bar{\nu}_e$  “disfavored” (KARMEN);
- 3 + 1 + 1 scheme works (finely tuned?);
- something completely different;

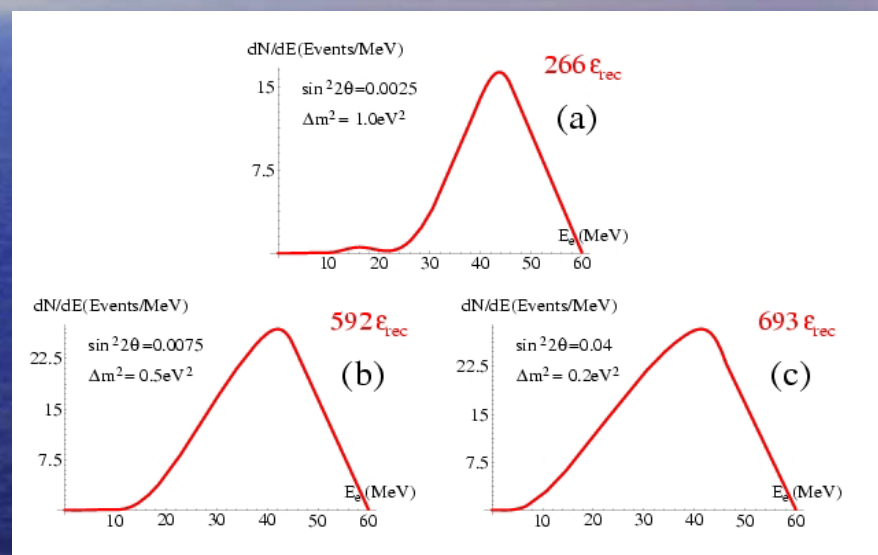
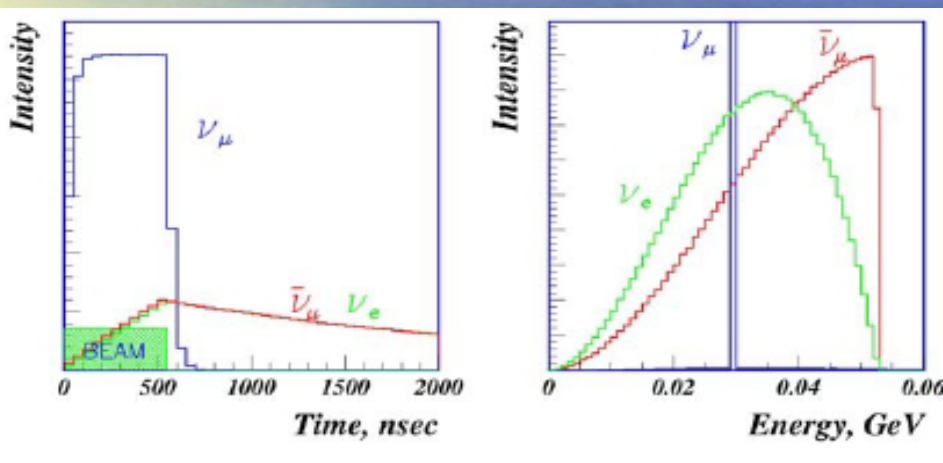


[this one gets my vote!]

If there is a signal, test SBL further ...

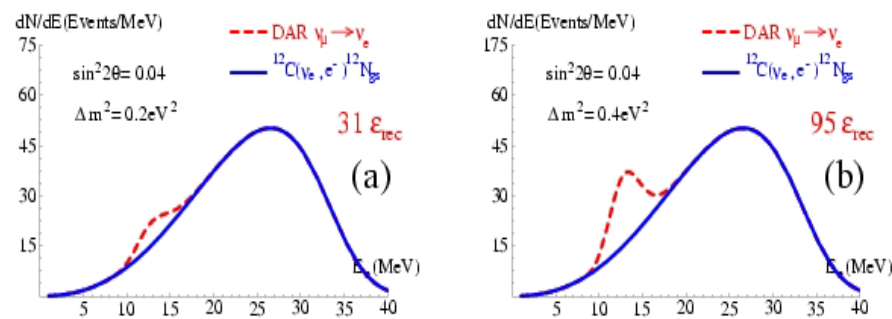
# Decay at Rest Source (Van de Water)

Idea: Use stopped pions and muons to better predict spectrum  
=LSND with higher intensity and much larger duty factor



nucl-ex/0309014  
hep-ex/0408135

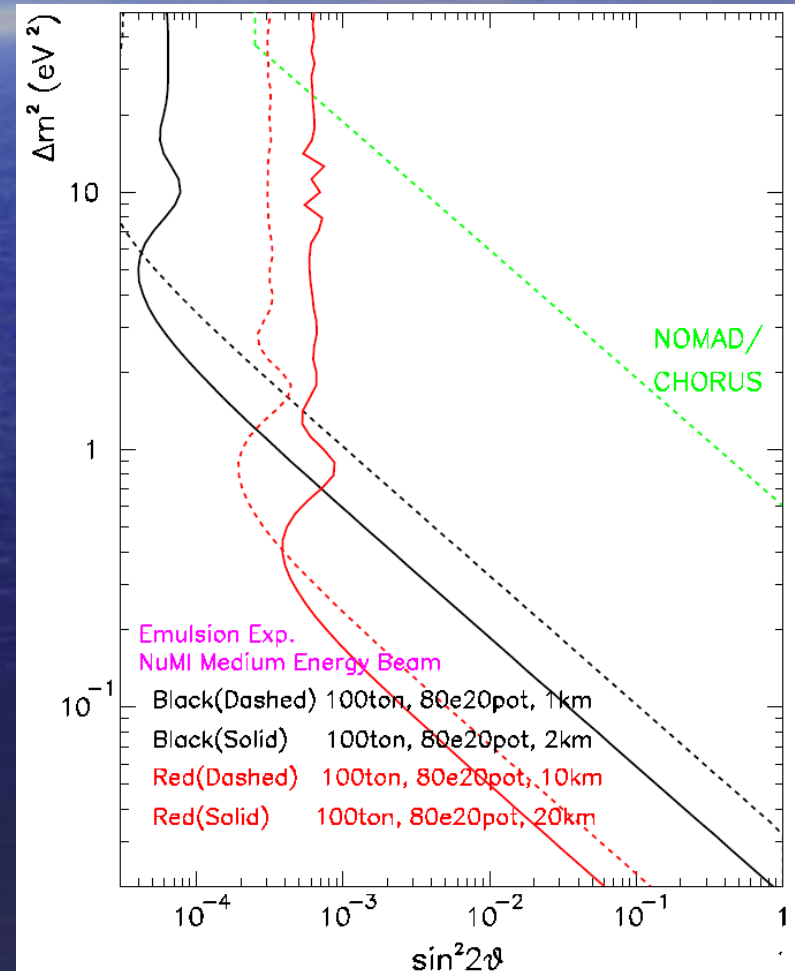
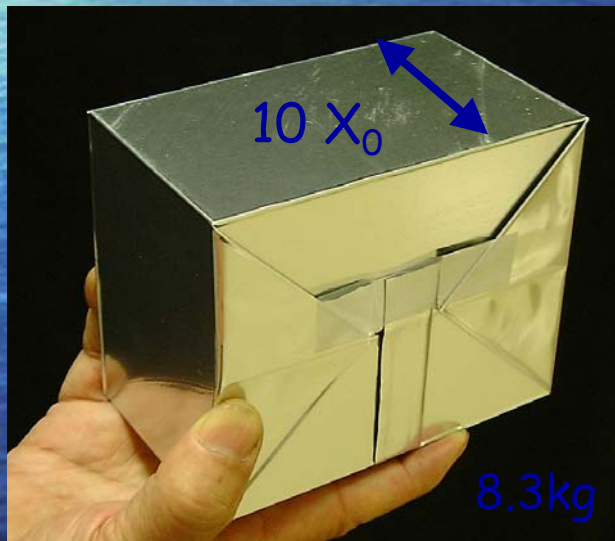
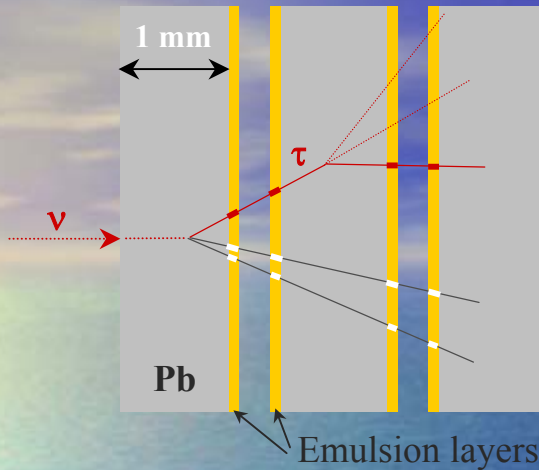
	FNAL (8 GeV)	FNAL (5 GeV)	SNS
P/yr	$4.9 \times 10^{22}$	$4.9 \times 10^{22}$	$2.2 \times 10^{23}$
DAR $\nu(\nu/P)$	1.5	0.9	0.13
DAR $\nu(\nu/\text{yr})$	$7.3 \times 10^{22}$	$4.4 \times 10^{22}$	$2.9 \times 10^{22}$





Check unitarity of mixing matrix:

NuMI numu to nutau (Bazarko)



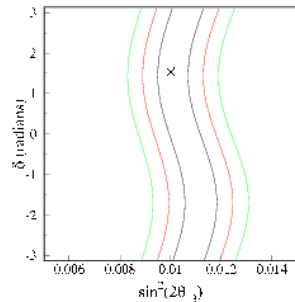


# Session VI

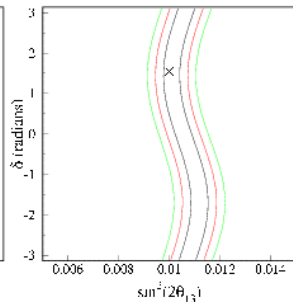
## Superbeam Experiments II

# FNAL-Japan/China (Fritz deJongh)

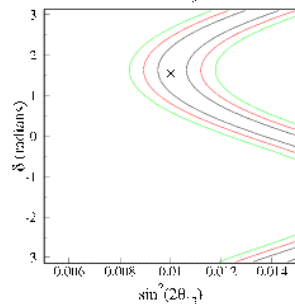
2 years  
with  
Fermilab  
beam.



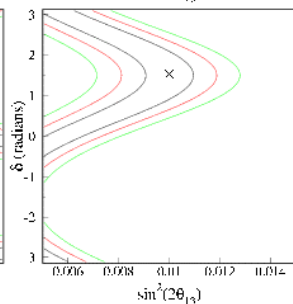
8 years  
with  
Fermilab  
beam.



2 years  
with JHF  
beam.

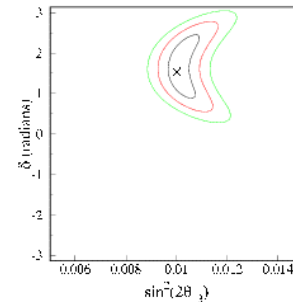


6 years  
with JHF  
anti-  
neutrino  
beam.

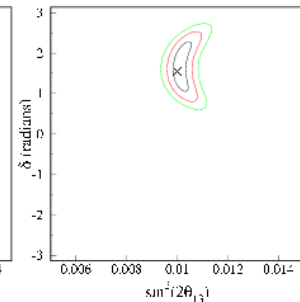


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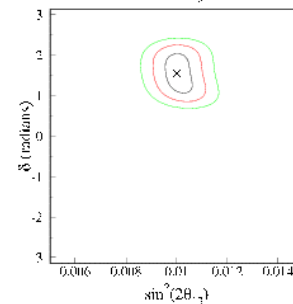
2 years  
with  
Fermilab  
2 years  
with JHF



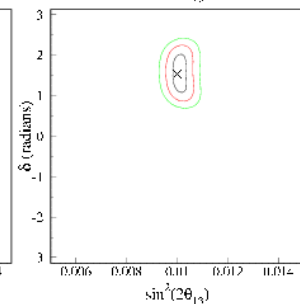
8 years  
with  
Fermilab  
8 years  
with JHF



2 years  
with JHF  
6 years  
with JHF  
anti-  
neutrino



8 years  
with  
Fermilab  
2 years  
with JHF  
6 years  
with JHF  
anti-  
neutrino



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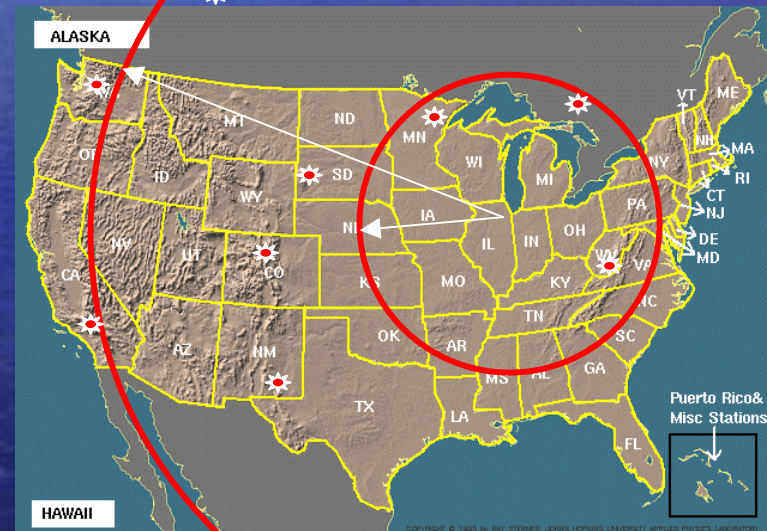
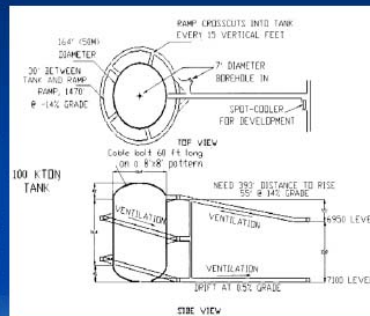
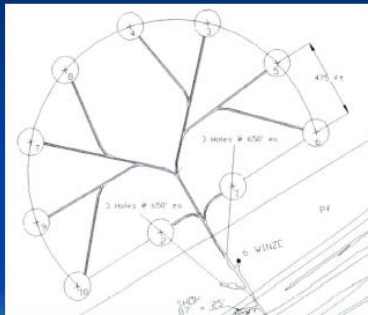
- Very long baseline good for  $\Theta_{13}$  ("Magic baseline" = about 7400 km)
- Together with short baseline very good resolution for  $\delta_{CP}$



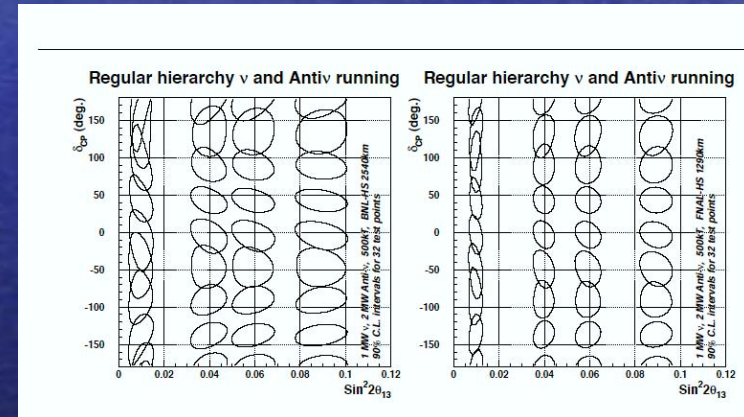
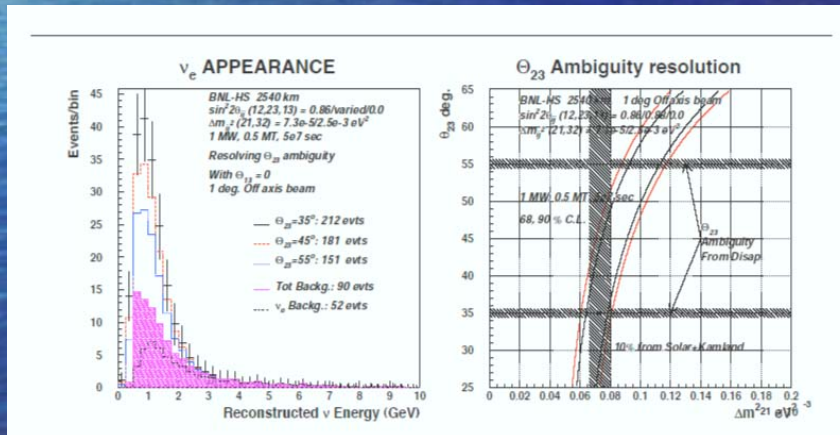
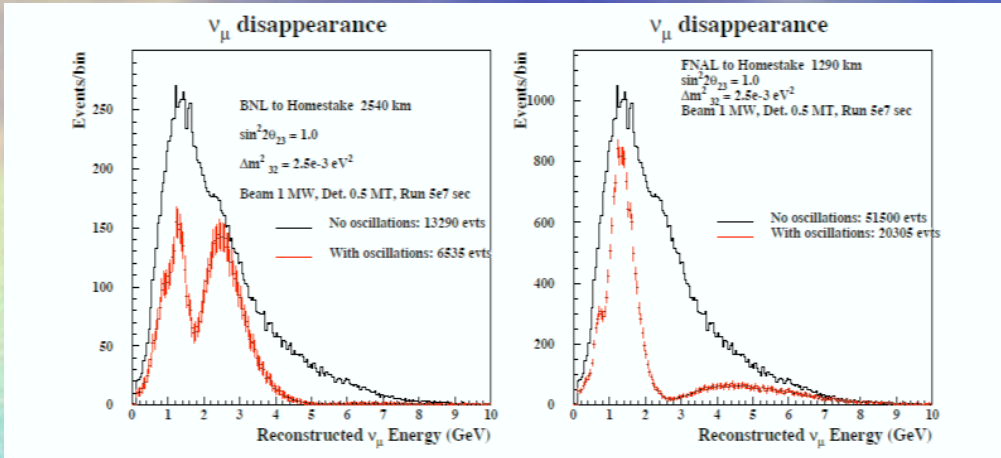
# PD connection with national underground Lab (G. Rameika)

- Need for underground lab from proton decay, Dark matter searches ...
- Massive detector good destination for long-baseline neutrino beams -> Synergy!

## Megaton Modular Multi-purpose Detector



# BNL- vs. FNAL- to Homestake (Diwan)



- FNAL-Homestake very competitive for  $\theta_{13}$  and also  $\delta_{CP}$
- BNL-Homestake has more solar oscillation contribution!

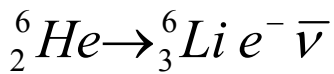


# Session VII

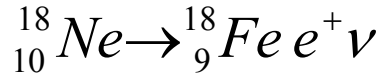
$\beta$ -Beam at Fermilab?



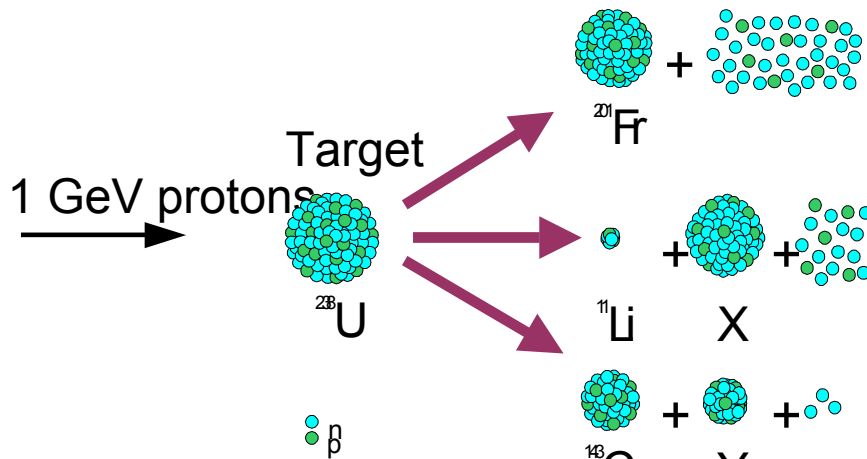
# Beta-Beams (Jansson)



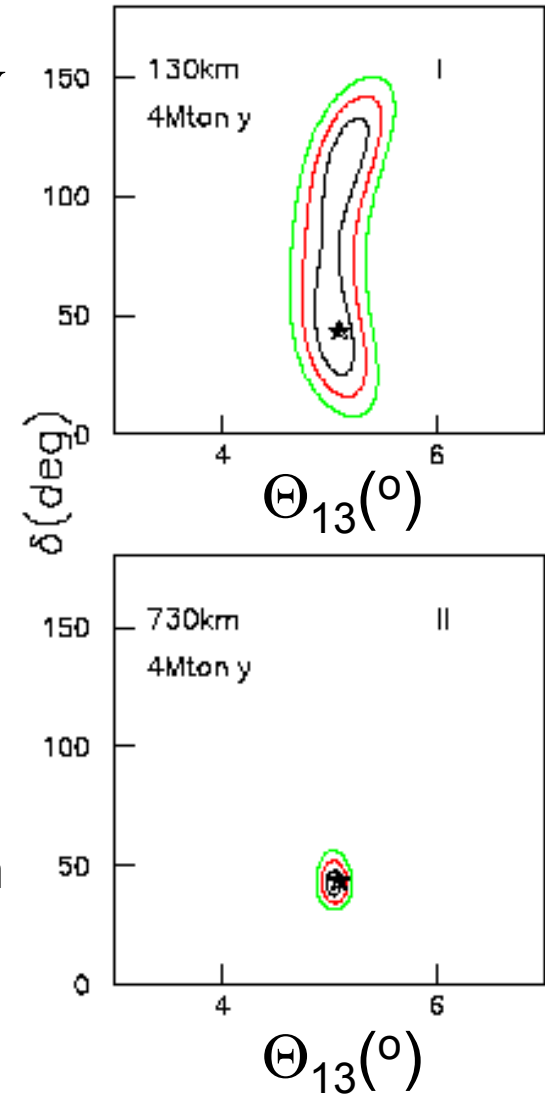
Average  $E_{cms} = 1.937 \text{ MeV}$



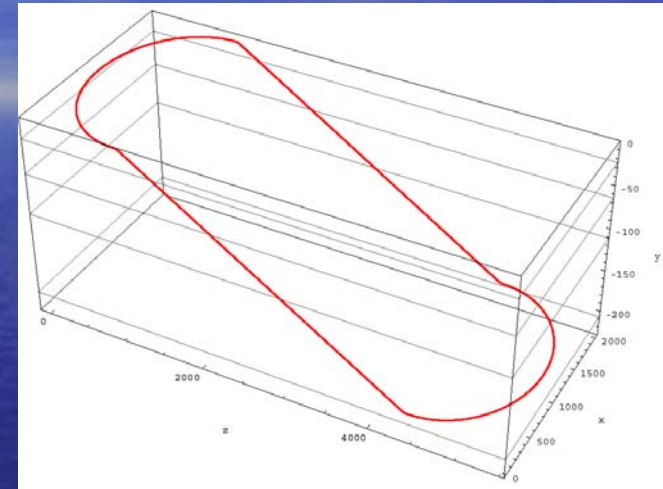
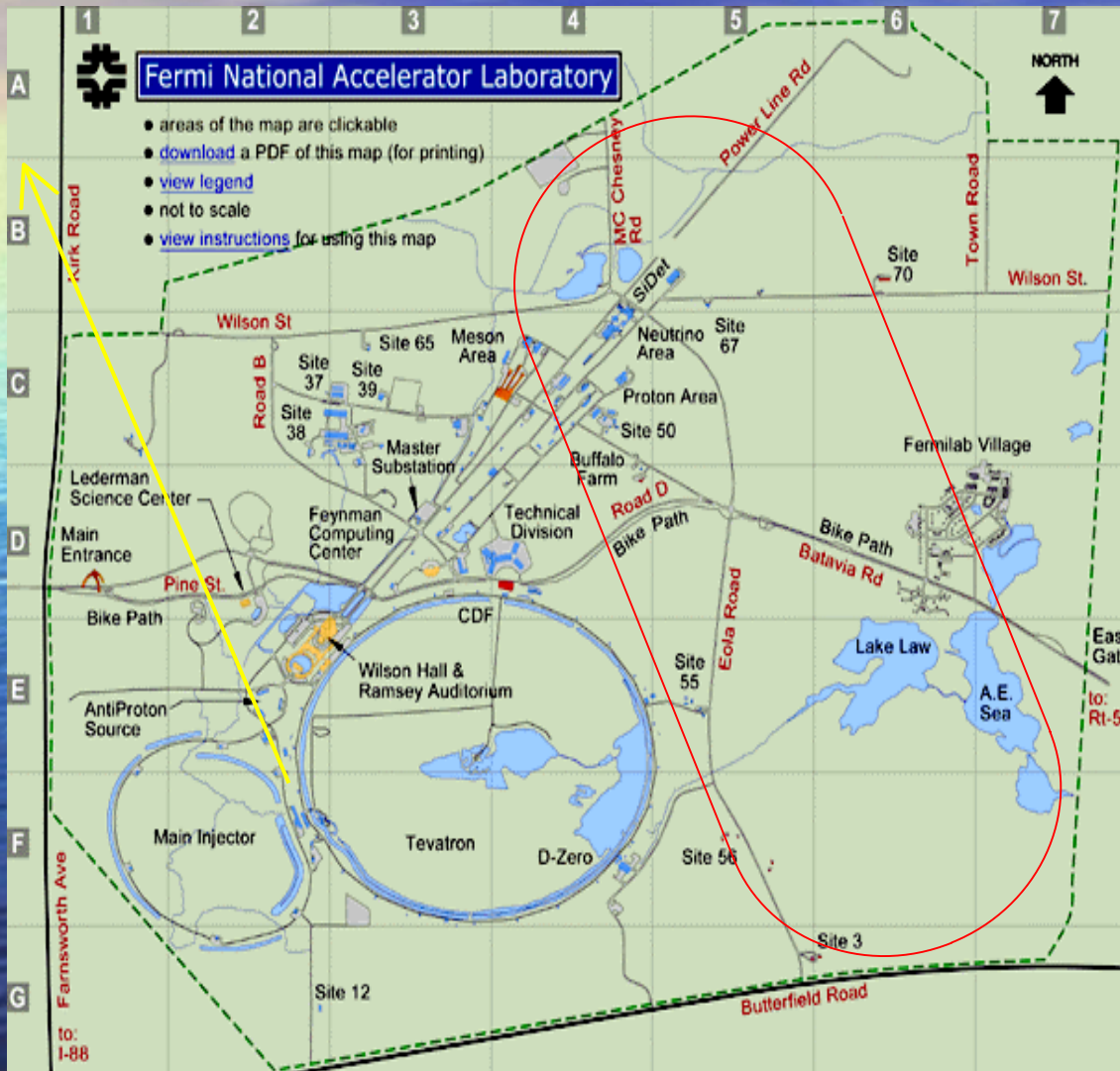
Average  $E_{cms} = 1.86 \text{ MeV}$



- Use about 250kW per Ion source (for  $\nu$  and  $\bar{\nu}$  running simultaneously)
- Decay losses need study (quenching? Mokhov in January ...)
- About  $1 \cdot 10^{13}$  ions of either type per cycle should yield an average loss power of about 1 W/m in Tevatron.



# Site Constraints of Beta-Beam at FNAL



**“Stretched Tevatron” aimed at Soudan**

**Total circumference:  
approximately 2 x Tevatron**

**320m elevation @ 58 mrad**

**26% of decays in  
Straight Section**

## 1) **Intro, purpose, and explanation of chapter layout**

## 2) **Osc theory summary (Parke, de Gouvea)**

- a) Introduction
- b) Neutrino mixing: Three-flavor neutrino oscillations
- c) Matter effects
- d) Summary of current parameter knowledge
- e) Appearance and disappearance channels Including: which measurements are interesting:
  - i.  $\theta_{13}$ ,
  - ii. CP measurements
  - iii. mass hierarchy
  - iv. deviations from max. Mixing
- f) Complementarity to reactor experiments
- g) What if MiniBOONE confirms LSND? -> Steriles, CPT violation ...
- h) Some other "new" physics possibilities

## 3) **Theoretical motivation for neutrino oscillation measurements (Antusch, Lindner, Kersten, Ratz)**

- a) Maybe some introduction about the generation of neutrino mass; Dirac/Majorana; see-saw
- b) Predictions from theoretical models (incl. GUTs, bottom-ups, anarchy etc)
  - i.  $\theta_{13}$
  - ii. Deviations from max. Mixing
  - iii. Mass schemes
  - iv. Maybe something about Dirac CP phase!?
  - v. Conclusion: Parameter predictions are within mid-term experimental reach
- c) Implications of RG running
  - i. Conclusions: zero  $\theta_{13}$  and  $\theta_{23}$  very close to maximal unlikely (with caveats)
- d) Impact of future measurements to model selection and theoretical predictions
  - i. Conclusion: Measurements help to select models or force theory to do it better

## 4) **Where we may be in 10 years time (Shaevitz, Brice)**

- a) Describe experiments that have yet to release results, but will have in 10 years time.
- b) Scenarios for where we may be in 10 years time
  - i.  $\text{SIN}^2 2\theta_{13}$  greater than  $\sim 0.04$
  - ii.  $\text{SIN}^2 2\theta_{13}$  between  $\sim 0.01$  and  $\sim 0.04$
  - iii.  $\text{SIN}^2 2\theta_{13}$  less than  $\sim 0.01$
  - iv. LSND oscillation confirmed by MiniBooNE
  - v.  $\text{SIN}^2 2\theta_{23}$  still consistent with 1
  - vi. Something unexpected

# Draft Table of Contents

## 5) **$\text{SIN}^2 2\theta_{13}$ Greater Than $\sim 0.04$**

- a) Can use existing NuMI beamline
- b) Nova (Feldman)

## 6) **$\text{SIN}^2 2\theta_{13}$ Between $\sim 0.01$ and $\sim 0.04$**

- a) Need new beamline or larger detectors
- b) Super Nova, other off-axis (Feldman)
- c) FeHo (Michael)
- d) Broadband scheme (Diwan)
- e) FNAL to China (de Jongh)

## 7) **$\text{SIN}^2 2\theta_{13}$ Less Than $\sim 0.01$**

- a) Search with experiments from previous chapter
- b) Betabeam (Finley and Jansson)
- c) Neutrino Factory (Geer)

## 8) **Other Possibilities**

- 1) LSND oscillation confirmed by MiniBooNE
  - i. Decay at rest source (Van de Water)
  - ii. NUMI numu to nutau & numu disappearance (Bazarko)
  - iii. Effect on LBL measurements
- a)  $\text{SIN}^2 2\theta_{23}$  still consistent with 1
  - i. Nova (Feldman)
- b) Something unexpected
  - i. ....

## 9) **Summary**



# Summary and conclusions

- Interesting discussions:
  - Staged approach versus one big jump
  - Importance of long distance for “solar” terms
  - Parallels with collider program?
  - ...
- Homework assignments
  - Writing for everybody
  - Gary Feldman will look at fluxes from 8 GeV protons to NOvA
  - How statistics limited is the NOvA  $\theta_{23}$  measurement?
  - ...

Thanks to all our great speakers!